

# Net-Zero Energy Building Enhancement for a Leadership in Energy and Environmental Design Platinum Educational Facility

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**Abstract:** In the United States, university buildings use 17% of total non-residential building energy per year. According to the NREL (National Renewable Energy Laboratory), the average lifecycle of a building in a university is 42 years with an EUI (energy use intensity) of 23 kWh/m<sup>2</sup>/y. Current building and energy codes limit the EUI to 16 kWh/m<sup>2</sup>/y for new school buildings; this benchmark can vary depending on climate, occupancy, and other contextual factors. Although the LEED (leadership in energy and environmental design) system provides a set of guidelines to rate sustainable buildings, studies have shown that 28%-35% of the educational LEED-rated buildings use more energy than their conventional counterparts. This paper examines the issues specific to a LEED-rated design addition to an existing university building. The forum, a lecture hall expansion of to an existing building at the University of Kansas, has been proposed as environmentally friendly and energy-efficient building addition. Comfort and health aspects have been considered in the design in order to obtain LEED platinum certificate. The forum's energy performance strategies include a double-skin facade to reduce energy consumption and PV (photovoltaic) panels to generate onsite energy. This study considers various scenarios to meet NZEB (net-zero energy building) criteria and maximize energy savings. The feasibility of NZE criteria is evaluated for: (a) seasonal comparison; (b) facility occupancy; (c) PV panels' addition in relation to double skin facade. The results of NZEB approach are compared to LEED platinum requirements, based on RoI (return on investment) and PV panel's efficiency for this specific educational building.

**Key words:** NZEB, double skin facade, energy plus, educational building, PV panels, LEED.

## 1. Introduction

In the US (United States), educational buildings are the fifth most prevalent institutional building type with approximately 309,000 buildings. Based on research conducted by the EIA (Energy Information Administration), educational buildings consume a total of 0.19 gigawatt per hours (614 trillion BTU (British thermal unit) of energy per year. For a typical university building, space heating, cooling, and lighting together account for nearly 70% of energy use [1]. For new school buildings, energy codes limit the EUI (energy use intensity) to approximately 16 kWh/m<sup>2</sup>/y [2]. However, the current average lifecycle of a building in a university is 42 years with a EUI of

23 kWh/m<sup>2</sup>/y [3]. Based on Ref. [4], universities need to begin reducing their greenhouse gas emissions by 3% per annum (pa) if they are to take any level of leadership in addressing the enormous problem of climate disturbance. Sustainable higher educational institutions will require efficient use of energy in educational buildings and environmental awareness within students and institutional staff.

The LEED (leadership in energy and environmental design) rating has been adopted as the standard for building sustainability. An analysis of measured energy use data from 100 certified buildings yielded that on average LEED buildings use 18%-39% less energy per floor area than their conventional counterparts [5]. However, another study shows that 28%-35% of LEED buildings use more energy than

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buildings without a LEED rating [6]. In addition, the USGBC (United States Green Building Council's) research suggests that a quarter of the new buildings that have been certified do not save as much energy as their designs predicted and that most of those buildings do not track energy consumption once in use [7]. One problem with the LEED rating system may be the wide scope of categories used to promote the reduction of energy use and emissions. The LEED program uses a point system based on a checklist of features for efficient energy use, water conservation, proximity to public transportation, indoor air quality, use of environment-friendly materials and native landscaping. The wide scope of the program could be linked to issues in optimizing building energy use. Another problem could be that the certification relies on deterministic energy models to predict how much energy a planned building will use, but USGBC officials and many experts [8] agree that such models are inexact and different simulation tools may cause different energy assessment results [9]. During the operation phase, a building may use more energy than was predicted in the design phase [5]. The sources for these discrepancies energy consumption are rooted in the uncertainty in the models used for predictions as well as variability in building occupancy and use [10, 11].

In this study, the NZE (net-zero energy) evaluation is proposed to compensate for the potential inefficiency of using a sustainability rating system to predict energy performance at the design stage and evaluate energy improvement scenarios. The combination of active and passive sustainable strategies is examined with the potential of achieving

NZEB (net-zero energy building) performance for a new addition to an educational building, the forum, at the University of Kansas. The forum's energy performance strategies include a double-skin facade to reduce energy consumption and PV (photovoltaic) panels to generate onsite energy. This study considers various scenarios to meet NZEB criteria and maximize energy savings. The feasibility of NZE criteria is evaluated for: (a) seasonal comparison; (b) facility occupancy; (c) PV panels' addition in relation to double skin facade.

## 2. LEED-Rated Building Addition

The forum at Marvin Hall is a new lecture hall and student commons area for the School of Architecture, Design and Planning at the University of Kansas (Fig. 1). The building addition incorporates both passive and active sustainable systems with intention to achieve LEED platinum certification. A living wall with vegetation is used to purify the air in the auditorium space; a water harvesting system is to route precipitation to a cistern; and PV panels on the roof are to generate energy on site. A DSF (double skin facade) system mediates the heat transfer between the exterior and interior of the building depending on the time of the year. Vertical louvers control the amount of light and solar gain entering the space. During summer time, the dual wall is vented to allow the heated air to escape and pull cooler air in underneath the addition, and in the winter time, the vents is closed allowing heated air to become trapped inside the cavity acting as a warm "blanket" for the addition.



**Fig. 1 The forum building addition with DSF technology.**

## 2.1 Modeling Approach

The software package design builder was used to simulate the forum building addition, and evaluate energy improvements scenarios. Design builder uses as its calculation engine EnergyPlus 8.1, developed by the US Department of Energy. The building addition was modeled as three zones: Zone 1 represented as an office building occupancy; Zone 2 as a lecture hall; Zone 3 as the cavity for the DSF (Fig. 2). Two ventilation methods were considered to evaluate the energy consumption of the building addition with the application of a DSF: (a) mechanical ventilation with the cavity space considered part of adjacent zones; (b) mixed ventilation (natural + mechanical) with the cavity space performing separately from the adjacent zones. The mixed ventilation modeling approach includes mechanical and natural ventilation with the DSF cavity zone used as a buffer to treat the air and ventilation load between the interior and exterior of the building. The main objective was to analyze the environmental conditions in the DSF, Zone 3, and the

resulting heating-cooling loads for the adjacent Zones 1 and 2 during extreme summer and winter conditions.

It was assumed that the vents in the cavity of the DSF are closed during the winter semester to prevent air exchange from outside and protect the inside air temperature, while the vertical louvers in the cavity of the DSF are open during office hours during the winter semester to provide natural sunlight and heat to the adjacent Zones 1 and 2. The DSF vents are kept open during the summer semester while no classes are in session except for staff meetings/events once a week. Similarly, the vertical louvers are kept open during the summer semester, so daylight can be used for lighting adjacent spaces and maintain the living wall. However, the vents and vertical louvers are closed once a week during staff meetings or events to avoid heat and extreme summer sunlight of Kansas.

## 2.2 Design Strategies to Achieve NZEB

Based on the approach to model the forum building addition, the research procedure conducted to evaluate

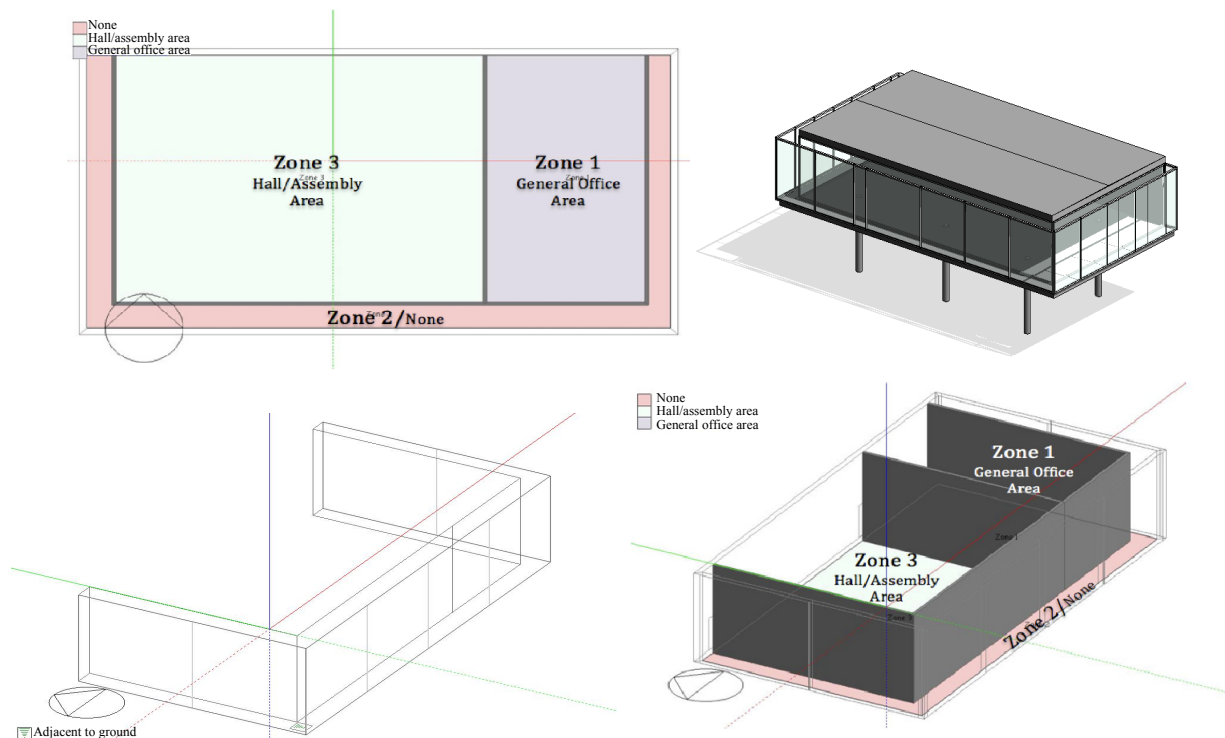


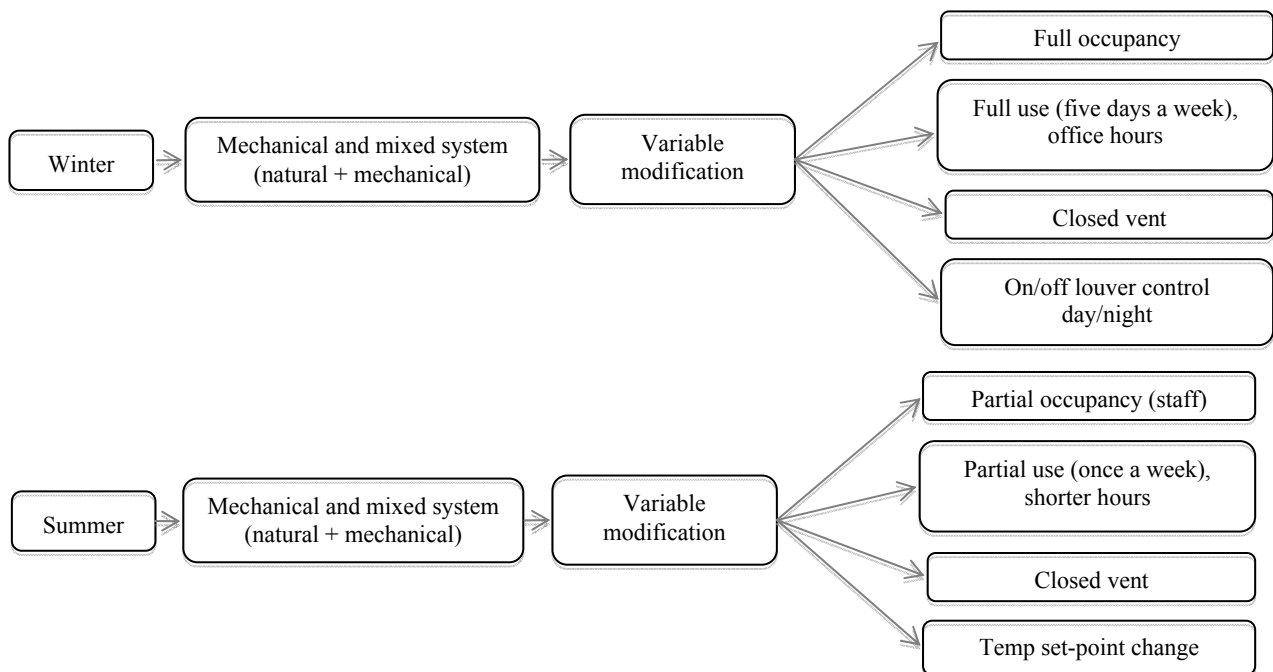
Fig. 2 Model of the forum in design builder.

the efficiency of the two ventilations methods involved a period of three months respectively for the winter and for the summer semesters (Fig. 3).

Table 1 shows the occupancy settings and ventilation modes for each season. During the winter season, the building addition performs during normal office hours (8:00 a.m.-5:00 p.m.) weekly from Monday to Friday while classes are in session. During the summer semester, there are no activities in this building addition other than weekly seminars for staff and group discussion once a week. The low occupancy and associated operation schedule provide an opportunity to reduce energy consumption. In order to analyze this possibility, the building addition operation schedule, occupancy and temperature set

point were modified and sensitivity analysis were conducted. Energy generation and consumption were quantified for the winter semester when the facility would be in full occupancy use; for the summer condition, the building operation schedule and temperature set points were modified due to the limited use of building addition.

Table 2 shows the scenarios identified for this study. Scenarios 1 and 2 were considered to provide a comparative picture of the energy demand during the winter semester. Scenario 3 was used to quantify the maximum energy demand for the facility during summer semester. Scenarios 4 to 8 were introduced as the alternative cases to identify the optimum solution while the building is in the minimum use in summer.



**Fig. 3 Research procedure.**

**Table 1 Occupancy level and ventilation modes for each season.**

Semester	Occupancy	Operation schedule hours	Days per week	Temperature set point (cooling (°F))	Ventilation mode
Winter semester	Full use	8:00 a.m.-6:00 p.m.	5	off	VAV (variable air volume) + outside air reset + mixed mode + open vertical louver
Summer semester	Low use	9:00 a.m.-3:00 p.m.	1	Original: 72°, Modified: 78°	VAV + outside air reset + mixed mode + close vertical louver

**Table 2 Eight defined scenarios and variables in this study.**

Scenario	Modeling approach and ventilation mode		Occupancy level	Season and temperature conditions
1	Mechanical HVAC (heating, ventilation and air-conditioning) system	-	Full occupancy	Winter semester
2	Mixed HVAC (natural + mechanical system)	-	Full occupancy	Winter semester
3	Mechanical HVAC system	Without vertical louvers in DSF cavity	Full occupancy	Summer semester
4	Mechanical HVAC system	With vertical louvers in DSF cavity	Full occupancy	Summer semester
5	Mixed HVAC (natural + mechanical system)	Without vertical louvers in DSF cavity	Full occupancy	Summer semester
6	Mixed HVAC (natural + mechanical system)	With vertical louvers in DSF cavity	Full occupancy	Summer semester
7	Mixed HVAC (natural + mechanical system)	With vertical louvers in DSF cavity	Low occupancy	Summer semester
8	Mixed HVAC (natural + mechanical system)	With vertical louvers in DSF cavity	Low occupancy	Summer semester with adjusted temperature set-point

**Table 3 PV panel improvement options.**

PV panel layout and improvement options	PV area (m <sup>2</sup> )	Energy generation (kWh/y)
Current layout (as designed)	1,084	21,366
Option 1 (100 % based on PV module)	2,168	42,731
Option 2 (full roof area)	2,600	51,246

**Table 4 Total energy consumption and generation in each scenario.**

Scenario	Predicted total energy consumption (kWh)	Type (heating or cooling)	Predicted energy generation (kWh/y)	Generation type (current (%), 100% or full roof of PV)
1	160,600.58	Heating	72,904	Current (%)
2	156,889.68	Heating	174,859	Full roof area
3	341,538.20	Cooling	72,904	Current (%)
4	171,986.40	Cooling	72,904	Current (%)
5	334,688.54	Cooling	72,904	Current (%)
6	164,089.70	Cooling	72,904	Current (%)
7	68,325.10	Cooling	72,904	Current (%)
8	45,021.52	Cooling	174,859	Full roof area

### 2.3 Energy Generation from PV Panels

The solar energy system output for the state of Kansas is about 6 h per day (EIA). When compared to fossil fuel-generated electricity, each kilowatt of PV electricity annually offsets up to 16 kg of nitrogen oxides, 9 kg of sulfur dioxides, and 2,300 kg of carbon dioxide (CO<sub>2</sub>). On average, modern PV solar panels produce 8-10 w/m<sup>2</sup> of solar panel area [12]. In order to maximize the energy generation by the forum building addition, two options were considered: (1) The number of PV panels was increased 100% based

on the panel modular dimension; (2) The total roof area was considered to analyze the potential of achieving NZEB criteria. The annual energy generation and improvement options can be seen in Table 3.

## 3. Results

Table 4 shows the overall picture of total energy consumption for each scenario alongside predicted energy generation and the type of generation in each case. It can be noted that Scenarios 1 and 3-7 were considered as alternative scenarios in order to predict

the optimum case for this building. The PV panel improvement options were applied to maximize the building energy performance for Scenarios 2 and 8 which were considered as the optimum solutions.

### 3.1 Winter Simulation Results

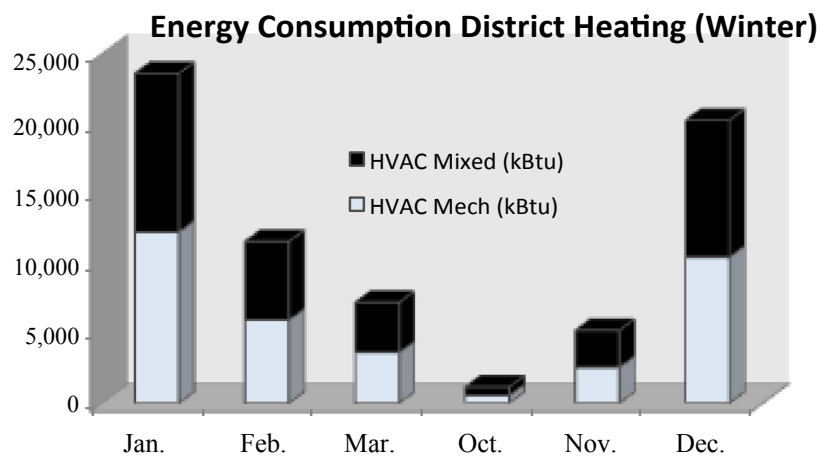
Table 5 and Fig. 4 show the predicted winter energy consumption for Scenario 1. The mixed ventilation outperforms the mechanical ventilation while the building is in full use in the winter semester.

### 3.2 Summer Simulation Results

Table 6 presents the parametric variation scenarios (Scenarios 6 to 8/Strategies 1 to 3) as three performance improvement strategies for site energy use and cooling load during summer season and Fig. 5

**Table 5 Winter heating use for Scenario 1.**

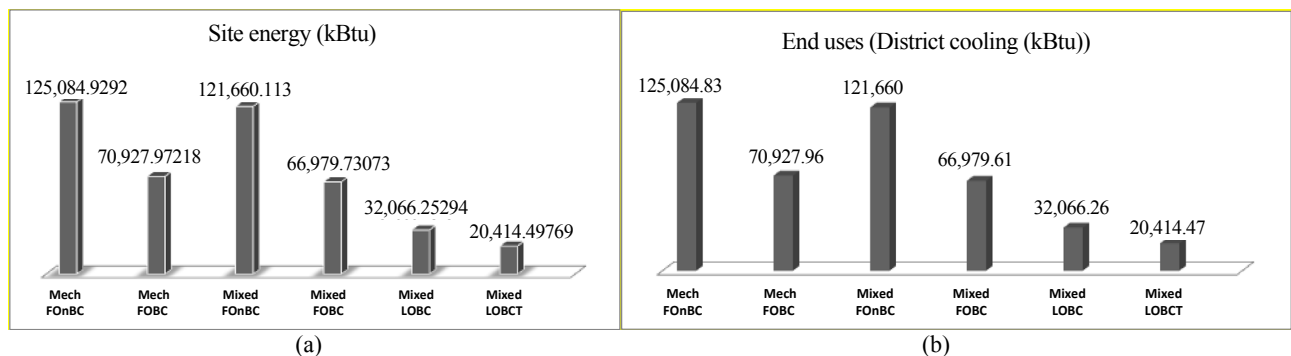
Ventilation mode	District heating—Winter (kWh)
Mechanical ventilation	34,586
Mixed ventilation	32,730



**Fig. 4 Winter monthly heating load for Scenario 1.**

**Table 6 Defined scenarios and performance improvement strategies (summer).**

	Mechanical ventilation		Mixed ventilation			
	Blind use potential (Scenario 4)		Base case (Scenario 5)	Strategy 1 (Scenario 6)	Strategy 2 (Scenario 7)	Strategy 3 (Scenario 8)
Worst case (Scenario 3)						
MechFOnL—FO (full occupancy), nL (no louver)	Mech FOL—FO, L (louver)		Mixed FOnL	Mixed FOL	Mixed LOL	Mixed LOLT
Site energy (kBTu)	216,453.37	101,058.44	213,028.54	97,110.09	36,258.84	24,607.05
Annual values—District cooling: HVAC (kBTu)	125,084.83	70,927.96	121,660	66,979.61	32,066.26	20,414.47



**Fig. 5 (a) Site energy; (b) cooling load.**

presents the obtained results in each scenario.

For both mechanical and mixed mode ventilation, Fig. 6 shows the impact of vertical louvers on the required site energy and the amount of cooling during summer semester. The vertical louvers in cavity can reduce both energy and cooling demand in the mechanical mode (Scenario 4) in comparison to no vertical louvers in the cavity (Scenario 3). The graphs show that the mixed ventilation performs better than mechanical mode even in the absence of vertical louvers in the cavity area (Scenario 5). Accordingly the respective performance improvement strategies (Scenarios 6 to 8/Strategy 1 to 3) to reduce the occupancy size and modify the temperature set point have a direct impact on both site energy and district cooling education. A set point is the temperature at which the HVAC system keeps the internal air temperature of a building and it has a major impact on the amount of energy the system uses. The closer the set point is aligned with the outside external temperature, the less energy is required for operation. According to Ashrae [13], space temperatures are targeted for 68° during the heating season and 72° during the cooling season during occupied hours which is within the range acceptable to 80% of the building occupants. As it mentioned earlier, the summer semester has less occupancy and this factor provides the opportunity to modify the set point temperature to reduce the energy and cooling demand. Fig. 6 shows that the influence of three performance

improvement strategies separately, and it can be seen that the improvement Strategy 3 can save almost 85% energy and 60% cooling load in comparison to base case scenario.

#### 4. Discussion

It should be noted that the mechanical method with and without vertical louvers in cavity for both seasons was calculated to analyze the potential of mixed method for this building addition in the extreme hot and cold temperature annually in the Kansas. Since the main focus of this paper is about the mixed ventilation method and the possibility of DSF to fulfill this requirement, after observing results for base case in both seasons, only mixed mode was considered as a strategic plan and optimum improvement for summer and winter seasons.

##### 4.1 Energy Consumption vs. Energy Generation

The mixed ventilation was observed to perform efficiently during the winter season to reduce energy demand and heating load and also the improvement Strategy 3 was selected as the best improvement option to reduce the summer energy demand and cooling load as seen in Table 7. The current area of PV panels on the building addition roof can generate 21,366 kWh/y energy annually and by increasing the numbers of PV panels to the full roof area, this number can be increased to 51,246 kWh/y. According to Table 7, the whole energy consumption of the building

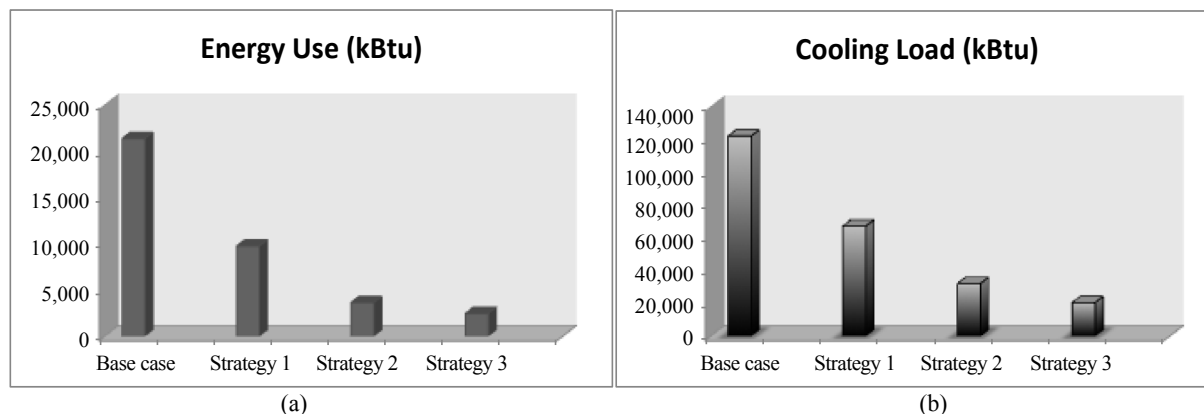


Fig. 6 Performance improvement strategies: (a) energy use; (b) cooling load.

**Table 7 Total yearly energy use and heating/cooling load.**

	Energy consumption (kWh)	Heating load (kWh)	Cooling load (kWh)
Summer (Strategy 3)	24,607.05	N/A (not applicable)	20,414.47
Winter (mixed ventilation)	123,401.09	33,488.59	N/A
Total energy demand (kWh)	148,008.14	-	-
HVAC total (kWh)	-	53,903.06	-
Total (kWh)	201,911.2		

**Table 8 Energy saving and generation cost.**

	Energy/HVAC	Cost (cent/kWh)	
Winter saving total (kBtu)	3,710.92		
Summer saving total (kBtu)	289,667.02		10.5
Total (kBtu)	293,377.94 kBtu/85,981 kWh		
Total saving/annual (\$)	9,028		
	PV addition	Cost	Total
Option 1 (100%)	72,902 kBtu/2,439 w	\$3/W	\$7,317
Option 2 (full roof)	101,955 kBtu/3,411 w		\$10,233

addition (HVAC loading + other energy use) accounts for 59,174 (kWh/y) and out of this number 51,246 kWh/y ( $\approx 87\%$ ) can be overlapped by the energy generation from the onsite PV panels which defines this building addition under NNZEB (near net-zero energy building) category.

#### 4.2 Cost Analysis of the Building Addition

According to the US EIA, the cost of electricity for the commercial building at the state of Kansas is 10.5 cent/kWh [14]. Application of mixed ventilation method during winter season and also applying improvement Strategy 3 (Scenario 8) during the summer semester could save \$9,028 annually at this building addition (Table 8). According to the NREL (National Renewable Energy Laboratory) [15], the median installed price of PV systems is \$5.30/W for residential and small commercial systems smaller than 10 kilowatts (kW) in size and \$4.60/W for commercial systems of 100 kW in size. For systems larger than 10,000 kW, generally the price ranges from \$2.50/W to \$4.00/W and this variability in pricing is due to the price difference across the states and various types of PV applications and system configurations. If we consider the mean \$3/W for PV installation at this building addition, the application of improvement Option 1 will cost \$7,317 and

improvement Option 2 (full roof area) which is the best scenario in order to achieve NNZEB will cost \$10,233 for this building addition. Therefore, the performance improvement strategies to reduce energy consumption will save the building addition managers \$9,028 annually and installation of PV panels to generate energy will require \$10,233 totally. The difference of \$1,205 can simply be paid off during the second year operation of the building addition and therefore, the cost analysis provides clear picture of benefit towards using renewable energy (PV panels) onsite after the first year (Table 8).

## 5. Conclusions

In this paper, the issues related to a LEED-rated design addition to an existing university building was examined. The forum was proposed as a lecture hall addition to an existing building at the University of Kansas with the features of environmental friendly and energy-efficient building addition and in order to obtain LEED platinum certificate, comfort and health aspects were considered in the design. The forum's energy performance strategies include a double-skin facade to reduce energy consumption and PV panels to generate onsite energy. This study considered various cases to meet NZEB criteria and maximize energy savings. The feasibility of NZE criteria were



evaluated for: (1) seasonal comparison; (2) facility occupancy; (3) PV panels' location in relation to double skin facade.

In order to analyze the impacts of each case on building energy performance, various scenarios were considered as alternative scenarios in order to predict the optimum case for this building. Scenario 2 and 8 were considered as the optimum solution and the performance improvement strategies of 100% and full roof area PV panel energy generation were applied to maximize the building energy performance. The mixed ventilation was observed to perform efficiently during the winter season to reduce energy demand and heating load and also Scenario 8 was selected as the best strategy to reduce the summer energy demand and cooling load. The current area of PV panels on the facility roof were increased to full roof area to overlap the energy generation with building energy consumption which categorize the building under NNZEB rating system. This strategy could save \$9,028 annually at this building and achieving NNZEB costs \$10,233 annually, where the difference of \$1,205 can simply be paid off during the second year operation of the building addition.

In conclusion, the NZEB concept provides a method to evaluate sustainable buildings focusing on solely on energy performance. An investment framework is used to evaluate strategies to achieve this standard of optimum energy efficiency in LEED-rated educational buildings. We find that this building type has great capacity to achieve the NZEB standard because of the variability in the occupancy and operation of the building, and the possibility to maximize the deployment of renewable energy systems.

For future direction, it is required to evaluate the optimum percentage of PV panels in every project to compensate for energy consumption while considering the life cycle cost of project and it is recommended to reduce the energy use in the building by methods mentioned in the case study before

consideration of PV panels installation onsite. The location of PV panels installation and the influence of location on project cost require further research in future studies.

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